Statistical Methods For Integrating Near-surface CO_2 Migration Modeling With Monitoring Network Analysis

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Abstract

Several different techniques have been developed for monitoring near-surface migration of CO_2. However, few have looked at how to best integrate the information from different measurement, monitoring, and verification (MMV) technologies to determine how best to place sensors in the field or how to interpret the information from multiple technologies to determine the magnitude or location of a leak that does occur.

In this work, we perform many simulations of hypothetical leakage scenarios with leaks of different magnitudes occurring around wells, along faults, and as a flux over a broad area. These simulations tell us how the CO_2 spreads within the near-surface environment for the different scenarios. At the same time, information on the different monitoring technologies, e.g., detection sensitivity, area of measurement, rate of false positives, are gathered. This information is incorporated into the development of a Bayesian Belief Network (BBN), which is a statistical tool that can be used to determine the likelihood that a leak of a given magnitude has occurred, given a detection of CO_2 at one or more monitoring sites. The BBN can also be used to help design a more efficient monitoring network with a lower rate of false positives or negatives. Once a generic BBN has been developed for near-surface CO_2 monitoring, it can be applied to a specific site with a given suite of monitoring technologies.

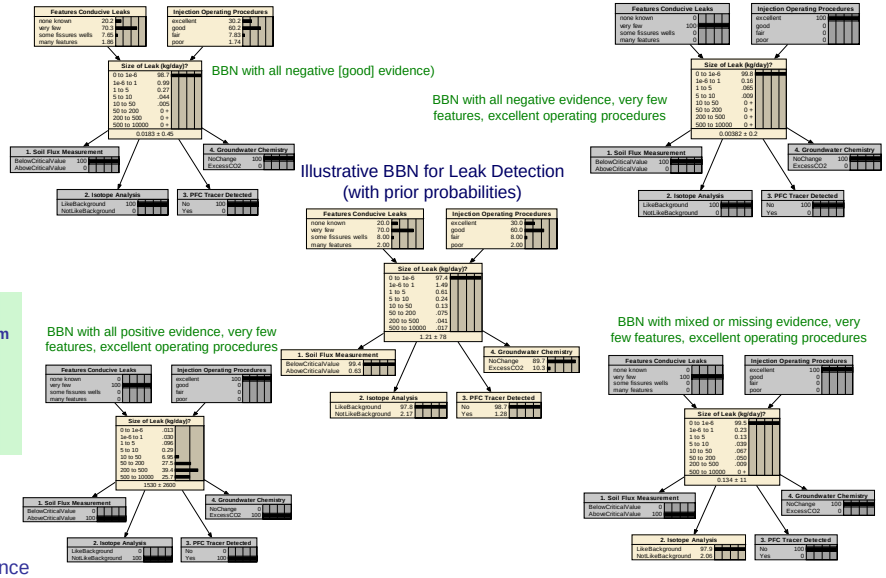
Objectives

- **Implement advanced CO_2 transport model to predict migration from different possible leakage events at a site: TOUGH2.**
- **Determine performance characteristics of leak detection technologies with given deployment for simulated leak events.**
- **Combine evidence from multiple detection systems to infer probability that a leak of a given size will be detected.**

Illustration

- Conditional probabilities are chosen for BBN by simulating random leaks and whether detection device registers a positive or negative
- Generate CO_2 flux measurements using TOUGH2 for a hypothetical, idealized site

Bayesian Belief Network (BBN) Development



Background

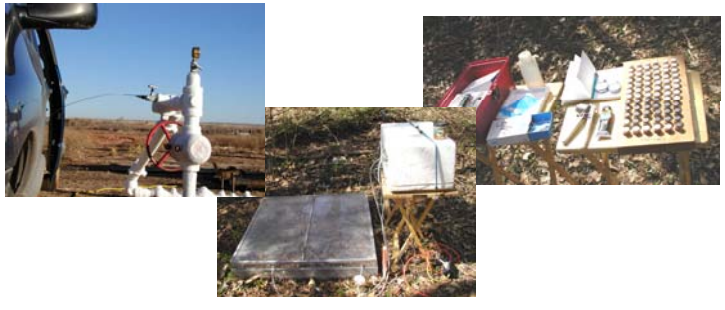
Model Implementation

- Site characterization
  - Multi-layered ground structure
  - Permeability
  - Porosity
  - Saturation rate
- Simulation of hypothetical and experimental injection scenarios
  - Vertical injection (point source)
  - Horizontal injection (line source)
  - Distributed leakage between two layers (distributed source)
- Investigate steady state seepage flux
  - Radial and local variation
  - Variation with injection rate, saturation rate, etc.
- Vadose zone effects

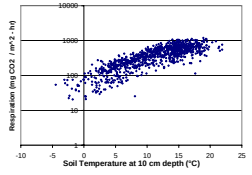
Combining Probabilistic Inference from Multiple Streams of Evidence

- Principal tool: Bayesian Belief Network (BBN)
  - **Influence diagram with nodes for events . . .**
    1. **Site conditions that affect leak probability**
    2. **The occurrence of a leak of a given size**
    3. **Measurement results from detection technology devices/networks**
  - **Arrows between events for causal influence**
    - **Characterized by conditional probabilities**
  - **Observations at any combination of nodes propagated through network to compute posterior probabilities**

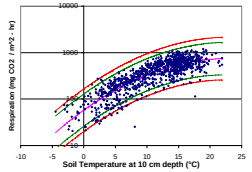
Monitoring Technologies



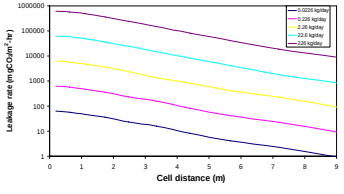
CO_2 Resp. Rate vs. Soil Temperature Howland Forest Site (1996-2003)



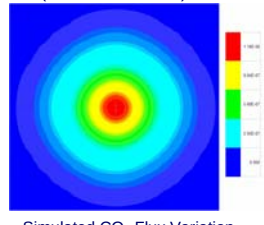
Quadratic Regression Model for Log(CO_2 Respiration) vs. Soil Temp. 95% and 99% Prediction Intervals



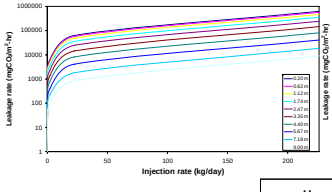
Simulated CO_2 Flux Variation (fn. of fugitive injection rate)



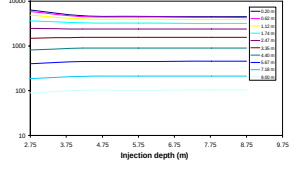
Simulated CO_2 Flux Variation (from leak at center)



Simulated CO_2 Flux Variation (fn. of radial distance from leak)



Simulated CO_2 Flux Variation (fn. of depth of fugitive injection)



Power Calculation

What is the probability that a leak of a given size will yield a CO_2 respiration rate above the x% prediction interval?